NASA-Supported Glaciological Studies in Antarctica

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Polar Radar for Ice Sheet Measurements (PRISM)

Project Personnel: Prasad Gogineni, Chris Allen, David Braaten, Victor Frost, Glenn Prescott, Arvin Agah, Costas Tsatsoulis: Institution: University of Kansas, Lawrence, KS
Cooperators: University of Alaska, NASA-JPL, Ohio State University, USACRREL, University of Chicago, University of Copenhagen, the Alfred Wegener Institute, University of Bristol, Australian Antarctic Division, Phoang Institute of Technology

Scientists and engineers at the University of Kansas are applying their expertise to develop and utilize innovative radar and robotic rovers to measure ice thickness and determine bedrock conditions below the ice sheets in Greenland and Antarctica. They are doing this through the auspices of a grant from the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA). This grant has been named PRISM (Polar Radar for Ice Sheet Measurements).

The data collected and the technology developed will enable researchers to do three things: a) determine the presence or absence of a film of water between the ice and the bedrock; b) measure ice thickness and c) map internal layers in both shallow and deep ice. The measurement of water at the bedrock level (basal water) is important because basal water lubricates the ice/bedrock interface and makes it easier for the ice to flow toward the ocean. Data on near-surface internal ice layers will be used to estimate the average, recent accumulation rate, while the deeper layers provide a history of past snow accumulation and flow rates. This combination of data will help earth scientists determine more unambiguously how quickly the polar ice sheets are melting and to make more accurate predictions of the effects of this melting on sea level rise. Scientists have postulated that excess water is being released from polar ice sheets due to long-term, global climate change; but there are insufficient data to confirm these theories. Understanding the interactions between the ice sheets, oceans, and atmosphere is essential to quantifying the role of ice sheets in sea level rise. This, in turn, allows earth scientists to more accurately predict the probability of significant sea level rise. A significant sea level rise would have a devastating impact on world population, agriculture, and ecosystems since nearly 60% of the world's population lives in coastal regions which would become flooded.

PRISM scientists plan to use synthetic aperture radar carried on ground level rovers to map the polar ice sheets and the bedrock. Ground-level radar of this type will provide a 2-D picture and more details than have previously been available from satellite imagery and airborne SAR radar. This radar will be able to operate in either monostatic or bistatic mode in order to produce the detail needed by glaciologists. Much of this project will focus on developing new technologies needed to carry out the project.

These new technologies include development of an "intelligent" and "collaborative" radar system; that is, one that can look at the data it is generating in real-time, determine if these data indicate that an area should be studied in more detail and then send that information to another radar system which is taking similar measurements only a few kilometers away.

PRISM engineers will design and build a semiautonomous ground rover capable of: a) withstanding the rigors of the polar environment, b) towing the radar safely and accurately, c) providing power for the radar systems and data analysis systems as well as the rover, and d) keeping track of the exact position of the radar units at all times.

PRISM scientists will also be developing a wireless communication system that operates in harsh polar environments to allow the rover and radars to communicate with one another as well as transmit near-real-time data back to other researchers and educators in distant locations.

For additional information go to: *http://www.ku-prism.org*

RADARSAT-1 Synthetic Aperture Radar Observations of Antarctica: Modified Antarctic Mapping Mission, 2001

Project Personnel: K.C. Jezek, K. Farness, The Ohio State University , Columbus, OH; R. Carande, X. Wu, Vexcel Corporation, Boulder, CO; N. Labelle-Hamer, Alaska SAR Facility, University of Alaska, Fairbanks, AK

The RADARSAT-1 Antarctic Mapping Project (RAMP) is a collaboration between NASA and the Canadian Space Agency (CSA) to map Antarctica using synthetic aperture radar (SAR). SAR is used because of its ability to image the surface in all-weather conditions and during the day or night. SAR also yields high-resolution imagery with good contrast between sea ice, glacier ice, and rocky outcrops as well as discriminating features on the ice sheet surface such as snow facies, crevasses, flow stripes, snow dunes, and even evidence of human activity such as aircraft landing strips and traverse tracks.

The first Antarctic Mapping Mission (AMM-1) was successfully completed in October1997 and yielded the first, high resolution, radar mosaic of Antarctica. The Modified Antarctic Mapping Mission (MAMM) occurred during the fall of 2000. MAMM has two goals, which complement science objectives for understanding the mass balance of the polar ice sheets and the response of the polar ice sheets to changing climate. The MAMM goals are:

1) Produce high-resolution image mosaics of Antarctica north of 80 $_o$ S latitude for change detection measurements and studies to understand the response of the ice sheet to climate change;

2) Measure the surface velocity field over coherent and/or trackable areas of the icesheet north of 80 $_o$ south latitude for ice dynamics studies and for exploring time variations in the surface velocity through comparisons with earlier data sets.

The MAMM effort is resulting in a new view of Antarctica that depicts in great detail the largest scale features associated with continental scale patterns of accumulation rate, smaller scale features such as the intricacies of cracks developed as ice from the continental interior spreads outward onto the ocean, and the motion of the ice itself. Mosaicking of the AMM-1 data is now complete and the results have been widely distributed to the science community. The results from MAMM will require several more years to process completely. But once done, the data will be similarly distributed through the NASA data centers.

For additional information go to: *http://www-bprc.mps.ohio-state.edu/*

GLAS / ICESat (Geoscience Laser Altimeter System / Ice, Cloud, and Land Elevation Satellite)

Project Personnel: Robert Schutz (Team Lead), University of Texas at Austin (schutz@csr.utexas.edu); Charles Bentley, University of Wisconsin, Jack Bufton, NASA/GSFC, Thomas Herring, MIT,Jean-Bernard Minster, University of California, San Diego,, James Spinhirne, NASA/GSFC, Robert Thomas, NASA, Wallops Flight Facility, H. Jay Zwally, NASA/GSFC

GLAS is a laser altimeter designed to measure ice-sheet topography and associated temporal changes, as well as cloud and atmospheric properties. In addition, operation of GLAS over land and water will provide along-track topography. For ice-sheet applications, the laser altimeter will measure height from the spacecraft to the ice sheet, with an intrinsic precision of better than 10 cm with a 70-m surface spot size. The height measurement, coupled with knowledge of the radial orbit position, will provide the determination of topography. Characteristics of the return pulse will be used to determine surface roughness. Changes in ice-sheet thickness at a level of a few tens of cm (anticipated to occur on a subdecadal time scale) will provide information about ice-sheet mass balance and will support prediction analyses of cryospheric response to future climatic changes. The ice-sheet mass balance and contribution to sea-level change will also be determined. The accuracy of height determinations over land will be assessed using ground slope and roughness. The height distribution will be digitized over a total dynamic range of several tens of meters.

Along-track cloud and aerosol height distributions will be determined with a vertical resolution of 75 to 200 m and a horizontal resolution from 150 m for dense cloud to 50 km for aerosol structure and planetary boundary layer height. Unambiguous measurements of cloud height and the vertical structure of thin clouds will support studies on the influence of clouds for radiation balance and climate feedbacks. Polar clouds and haze will be detected and sampled with much greater reliability and accuracy than can be achieved by passive sensors. Planetary boundary layer height will be directly and accurately measured for input into surface flux and air-sea and

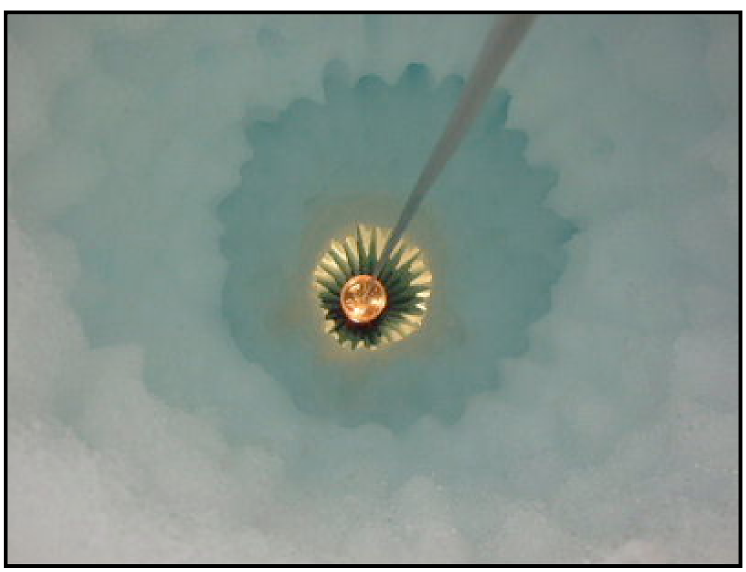
air-land interaction models. Direct measurements of aerosol vertical profiles will contribute to understanding of aerosol-climate effects and aerosol transport.
The GLAS laser is a diode pumped, Q-switched Nd:YAG laser with energy levels of 75 mJ (1.064 µm) and 35 mJ (0.532 µm). The pulse repetition rate is 40 pulses/sec, and the beam divergence is approximately 0.1 mrad. The infrared pulse is used for surface altimetry, and the green pulse is used for atmosphere measurements. The altimeter uses a 100-cm diameter telescope.
In the 120 days following launch, the ground track will repeat in 8 days to provide multiple overflights of ground verification/validation sites. The main mission will use a 183 day repeat track.

The ICESat Mission begins with a launch on a Delta II (Model 7320) Expendable Launch Vehicle (ELV) late in 2002, into a near polar Low Earth Orbit (LEO) at an altitude of 600 km with an inclination of 94 degrees. The spacecraft will accommodate the GLAS instrument which is currently estimated at a mass not to exceed 300kg and power of 330 W (each including 20% contingency), to fully achieve the EOS requirements.

For additional information go to*: http://www.csr.utexas.edu/glas*

Antarctic Borehole Probe

Project Personnel: Alberto Behar (Alberto.Behar@jpl.nasa.gov); NASA/JPL, Frank Carsey, NASA/JPL; Arthur 'Lonne' Lane, NASA, JPL; Barclay Kamb, California Institute of Technology; Hermann Engelhardt, California Institute of Technology.



The Antarctic Ice Borehole Probe mission was a glaciological investigation, performed in the 2000 - 2001 Antarctic field season. The purpose of the mission was to acquire visible-light images and video in a hot-water drilled hole in the West Antarctic ice sheet at IceStream C on the West Antarcit ice sheet. . The objectives of the probe are to observe ice-bed interactions with a downward looking camera, and ice inclusions and structure, including hypothesized ice accretion, with a side-looking camera. The Probe mission will also serve as a stepping-stone in the development of technology to acquire data in extreme ice and liquid environments. The information and experience will aid projects involving exploration in ice/liquid environments, including missions to Lake Vostok in Antarctica, Mars Polar Caps and Europa, Jupiter's moon.

During the 2000/2001 season, the borehole probe was successfully deployed in three holes drilled with the CalTech hot-water drill system. Each of the holes encountered bedrock at 1000 - 1200 meters below the ice surface. In all cases the combination of downward- and sideward-looking cameras displayed excellent imagery of both the ice and bed. Transitions from firn>bubbly ice>clear ice>debris-laden ice are clearly seen in the camera images as is the nature of the contact of the glacier bed with the underlying till. In the case of the third borehole, a 1.4 m deep, water-filled cavity was encountered between the base of the ice sheet and the top of the till.

Since the 2000/2001 season in Antarctica , the probe has been deployed at the Black Rapids Glacier in Alaska with equally successful results.

For additional information go to:

http://helios.jpl.nasa.gov/~behar/JPLAntIceProbe.html

Integrated Cryobot Experimental Probe

<u>Project Contacts</u>: Frank Carsey (*fdc@pacific.jpl.nasa.gov*), Lloyd French, Wayne Zimmerman, NASA/JPL

Probe Mission:
The Integrated Cryobot Experimental (ICE) Probe, Cryobot, is now two years into development for mobility technology in ice. The project will develop new technology to enable deep subsurface exploration and scientific investigation in icy earth and planetary environments.

Purpose:

The project goal is to develop new technology that allows vertical ice mobility, and to support subsurface exploration in continental-scale ice masses on Earth and other terrestrial planets. Controlled, long range mobility in ice sheets has never been reliably demonstrated, although attempted, past a 1 kilometer (0.6 mile) range. The Cryobot will achieve significant range and reliability using a system designed to provide optimal heat transfer efficiency along with control and mobility. Technological advances are needed in areas of planetary protection, navigation, instrumentation, sample handling, tether management and communication. In the future, this project will accommodate such scientific objectives as, studying Earth's past climates and ice dynamics science, Europan ocean and in-situ exploration, Titan prebiotic exploration and Mars exploration, climate history science, and exobiology science.

Description:

The project is in its second year of development. During the first year, a prototype was designed and fabricated. In September 2000, the probe successfully completed a five meter melt test. The second year expands the probes depth, control steering, and instrumentation capability. The second year will culminate in a 12 ft descent in simulated Mar's ice. When funded for a third year, models will be rendered to determine Cryobot performance in a Europa-type environment.

The Cryobot descends through ice using a joint passive (resistance heaters) and active (hot water drilling) system. The hot water drilling system heats and expels melt water against the ice melt-front allowing the probe to descend. The probe will be tethered to provide a suspended orientation, a constant distance from the ice interface, power and communication.

Features:
The Cryobot contains many distinct features for its success and development. The probe will have a hybrid of active and passive melting. This will be done through a water heating subsystem and a jetting subsystem. The system considerations and requirements include hull design for different pressures and temperatures, power, fluid dynamics, thermodynamics, data systems, monitoring sensors, communication and environmental factors. The probe's active melting design will be based on experimentation results with instrumentation, power consumption, pressure, water velocity, temperature and flow rate. The probe will

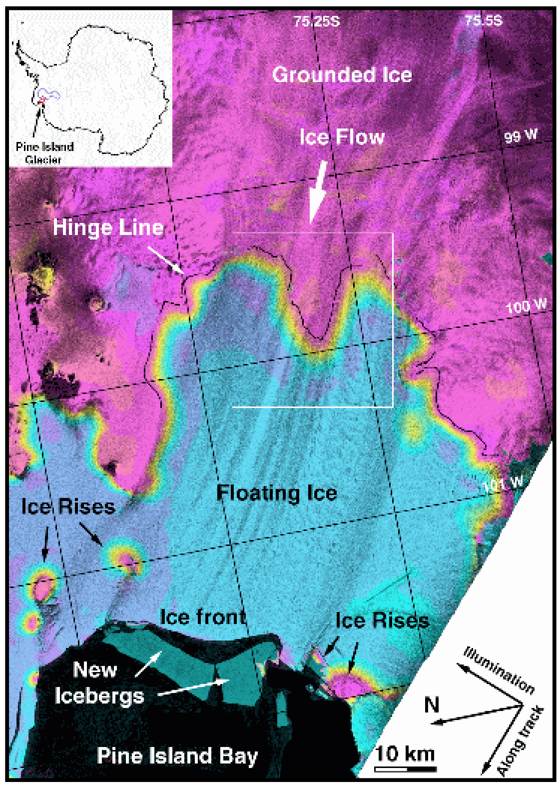
have limited engineering instrumentation to ascertain state data and some limited means for obstacle avoidance. A camera and chemical sensor are under development and will provide science data. The tether to be developed for this project will provide power and command ability to the probe and also return data information from the probe. The command station and probe power supply will be located on the ice surface where team members will monitor and control the probe's health and descent.

For additional information go to: *http://Fuego.jpl.nasa.gov/general.htm*

Synthetic Aperture Radar for Glaciology Research

Project contact: Eric Rignot, NASA/JPL (*eric@pib.jpl.nasa.gov*)

Synthetic Aperture Radars (SAR) produce all weather, day and night, high resolution images of the Earth's surface providing useful information about the physical characteristics of the ground and of the vegetation canopy, such as surface roughness, soil moisture, tree height and bio-mass estimates. By combining two or more SAR images of the same area, it is also possible to generate elevation maps and surface change maps with unprecedented precision and resolution. This technique is called InSAR. With the advent of spaceborne radars, InSAR has been applied to the study of a number of natural processes including earthquakes, volcanoes, glacier flow, landslides, and ground subsidence.



Spaceborne synthetic-aperture radar interferometry (InSAR) is a powerful remote sensing tool for measuring glacial motion with millimeter-scale precision, over extensive areas, at an unprecedented level of spatial details. This technique has been used to map the detailed topography and vector velocity of the Greenland and Antarctic Ice Sheets, the tidally-induced vertical motion of large areas of floating ice, and study rift propagation precursor to large calving events on Antarctic ice shelves. The results are an important source of information for determining the current state of mass balance of outlet glaciers and ice sheets, for estimating their contribution to sea level rise, for capturing dynamic changes such as grounding-line retreat and flow acceleration, for predicting future calving events, and eventually better constraint predictions of the evolution of those ice masses in a changing climate.

Recent results of project work report on bottom melting, grounding-line retreat, surface motion acceleration and ice-shelf changes in several antarcitc locations.

For additional information go to: *http://www-radar.jpl.nasa.gov/glacier*